Exploiting the Phase in Diffusion MRI for Microstructure Recovery: Towards Axonal Tortuosity via Asymmetric Diffusion Processes

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Exploiting the **Phase** in **Diffusion MRI** for Microstructure Recovery: Towards Axonal **Tortuosity** via **Asymmetric** Diffusion Processes

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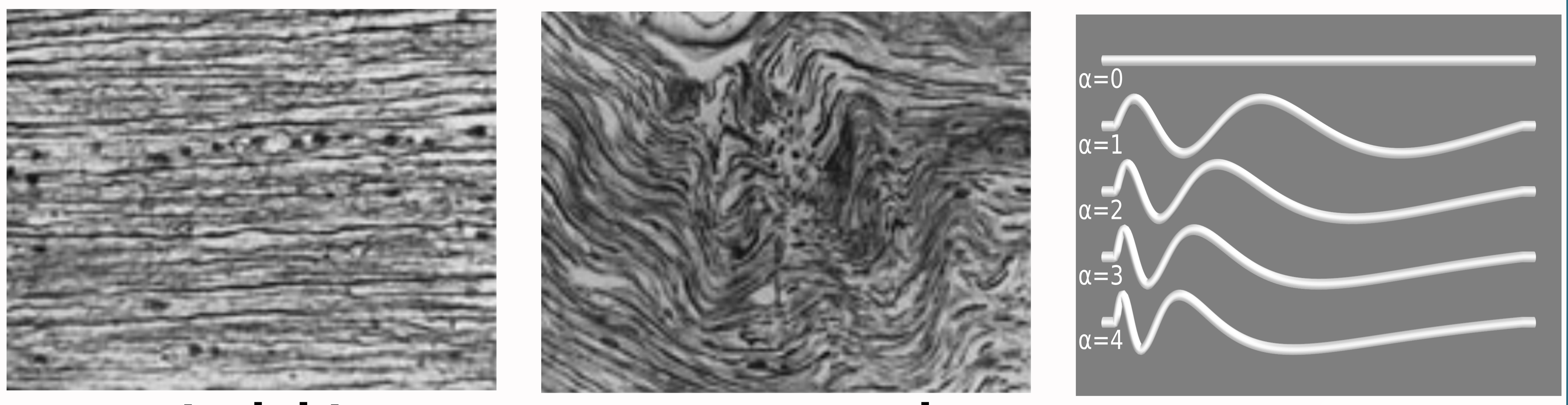
We derive the **Ensemble Average Propagator** (EAP) for the case of straight axons (White Matter tissue elongation) and for undulated axons having **different tortuosity rates** (WM tissue compression). We show that under the hypothesis of having both the **Magnitude and Phase** of the dMRI signal we can **quantify the asymmetry** of the EAP which is related to the rate of tortuosity variation in the compressed axon.

1 Undulated and Tortuous Axons

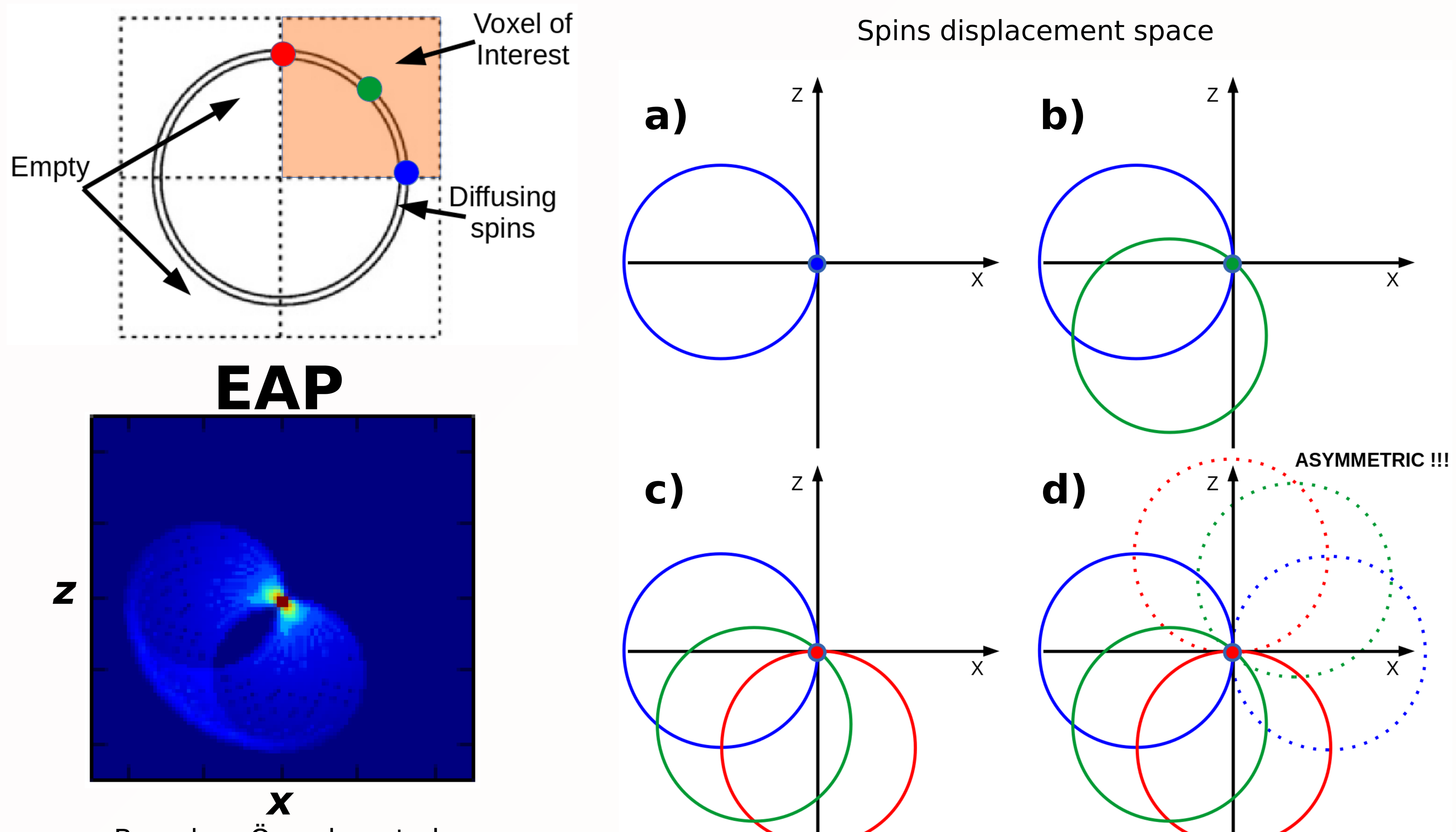
Tortuous and undulated white matter axons are found in pathological scenarios associated with axonal elongation or compression.

White Matter Tissue **Models**



Axonal compression leads to **asymmetry** in the **E**nsemble **A**verage **P**ropagator (**EAP**). What is asymmetry?

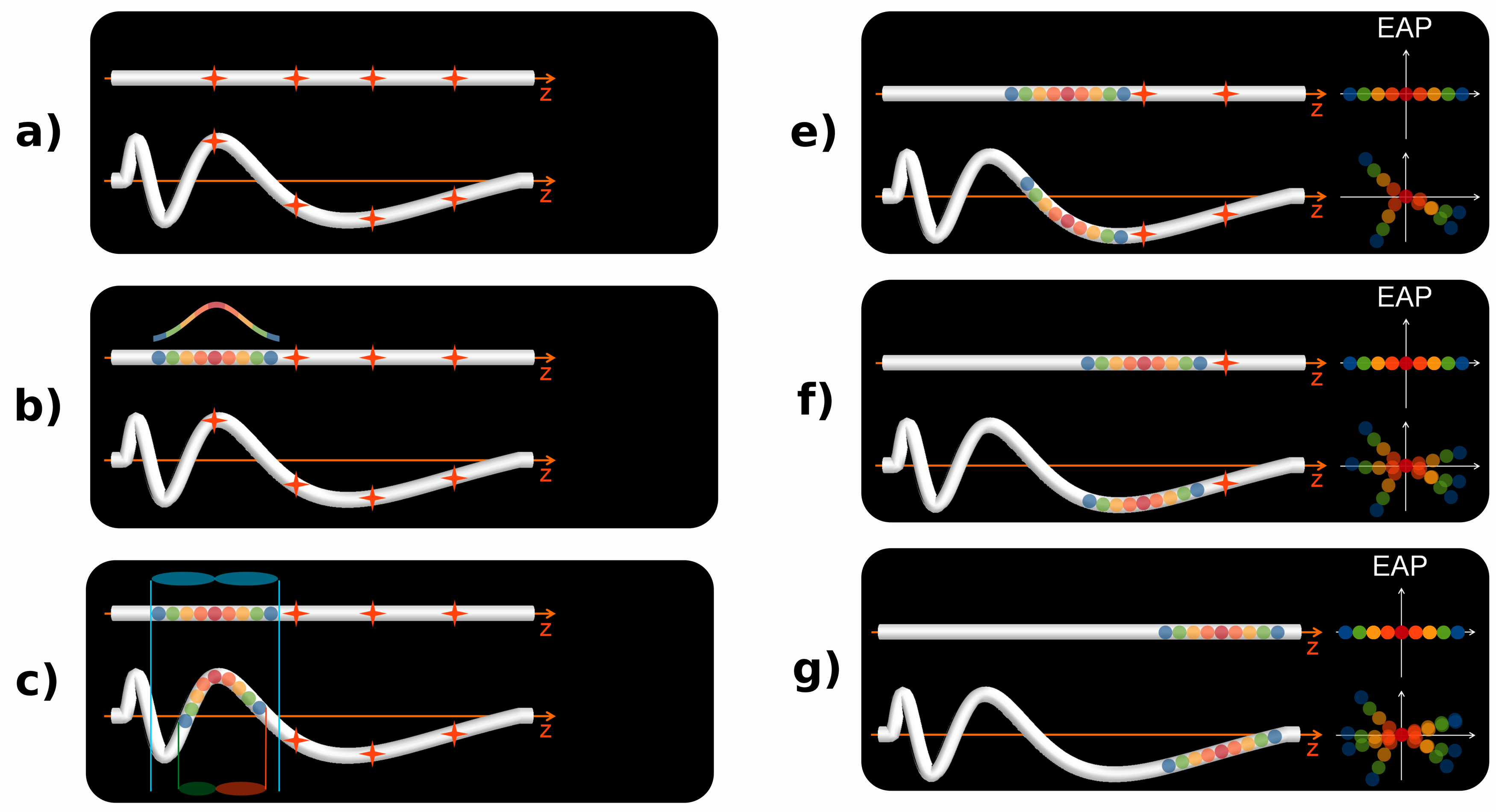
2 EAP asymmetry: an example

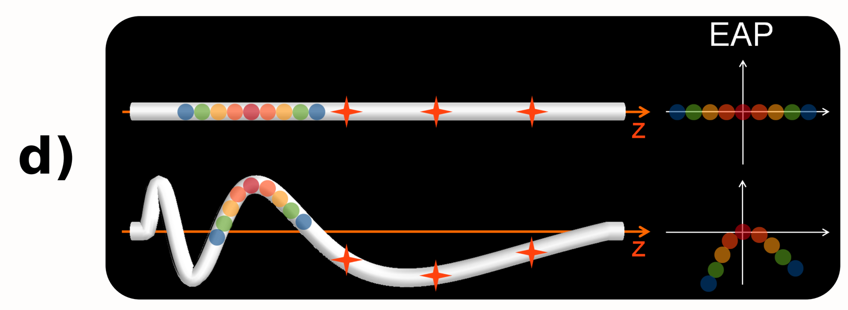


Based on Özarslan et al.

3 EAP of Tortuous Axons: derivation

We hypothetically sample a **straight** and a **tortuous** axons in **four sampling points** (stars) in order to obtain an empiric representation of the bidimensional EAP. At each point Gaussian diffusion is assumed.

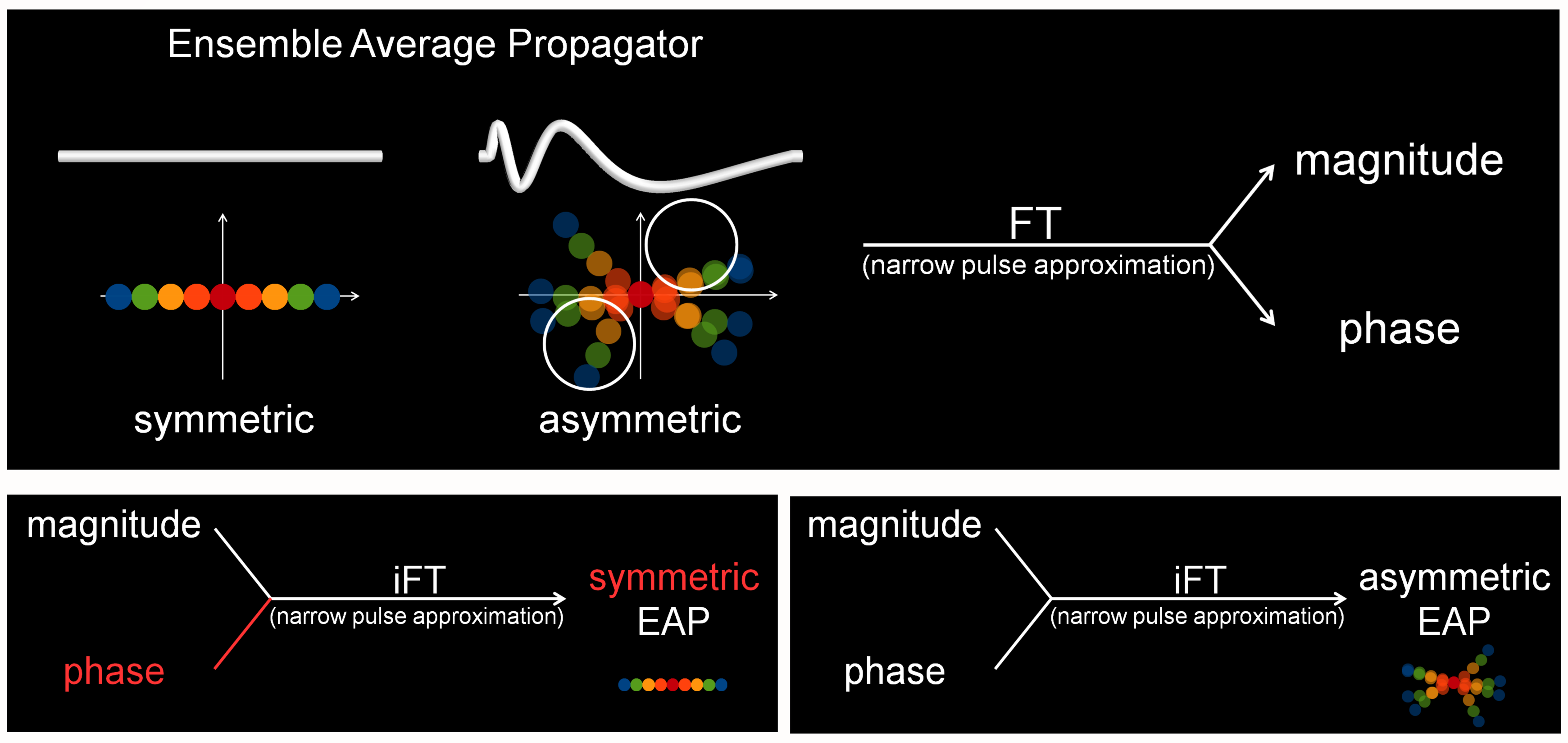




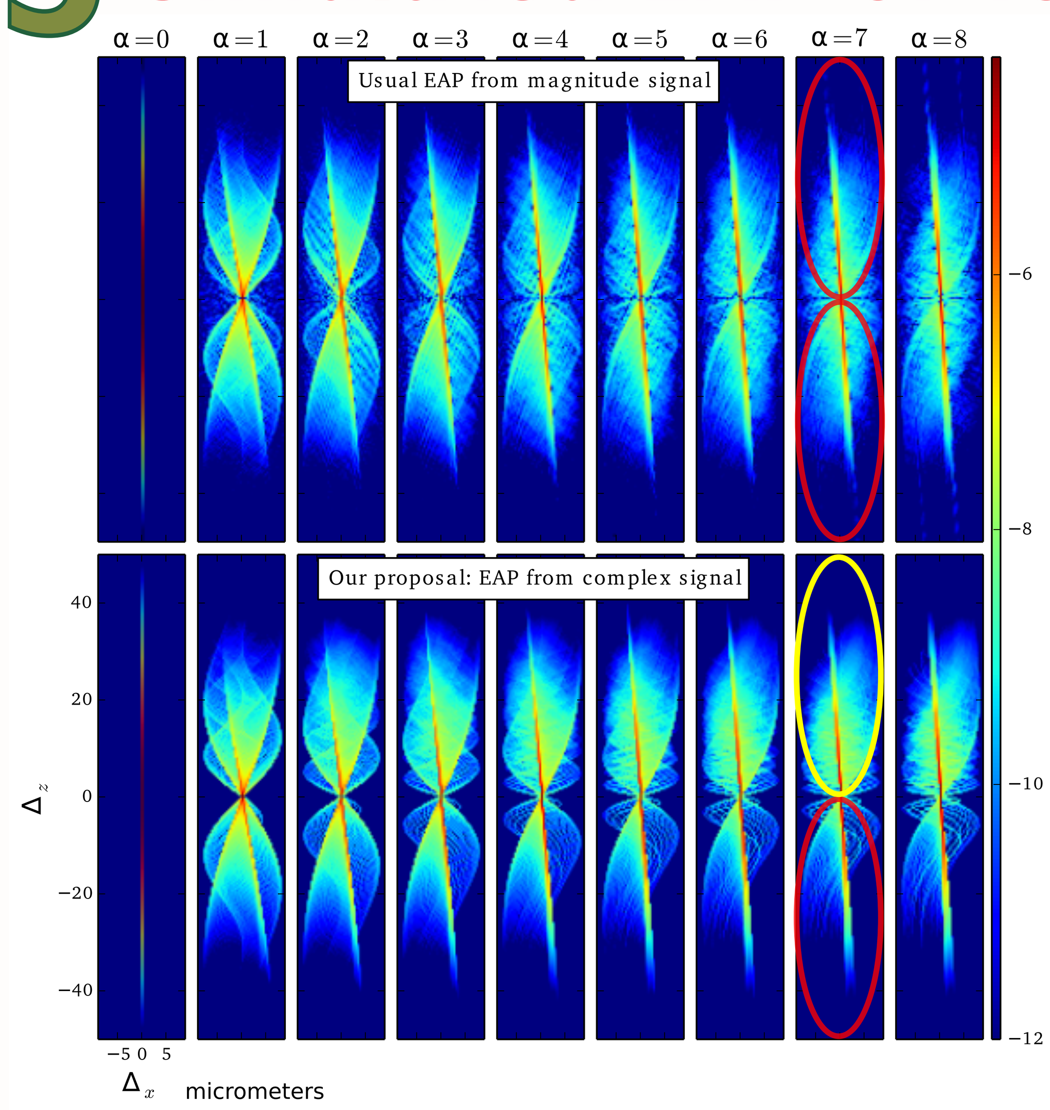
Spins diffusing along the tortuous axon displace differently, according to the axonal shape, for each sampling point.

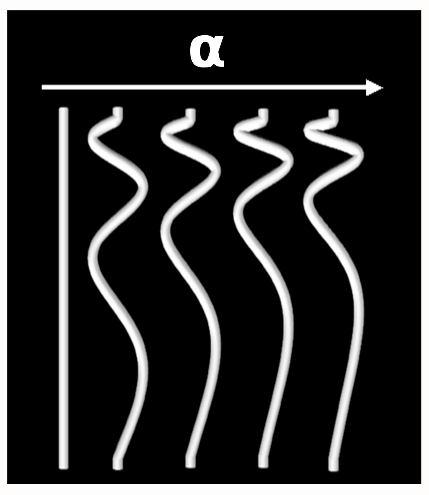
4 EAP asymmetry and PHASE

The asymmetry of the EAP can be appreciated from the complex Diffusion MRI signal. The signal's Phase carries information.



5 Simulated EAP of Tortuous Axons

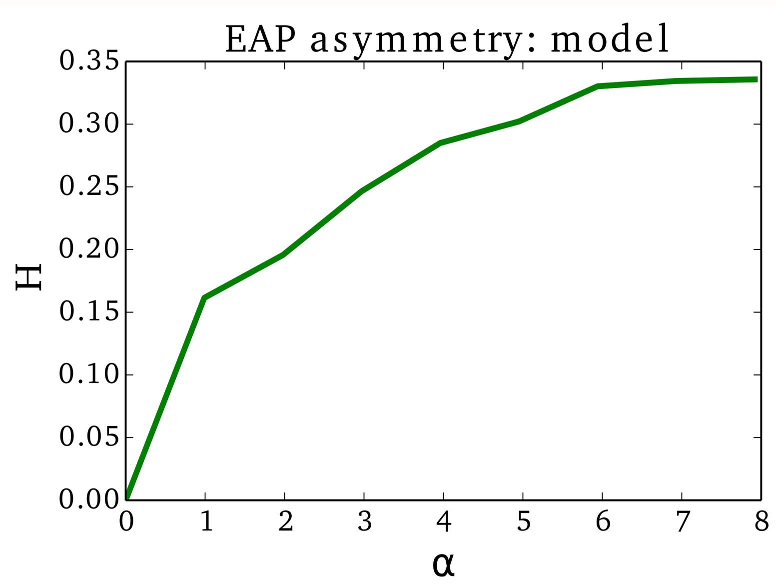


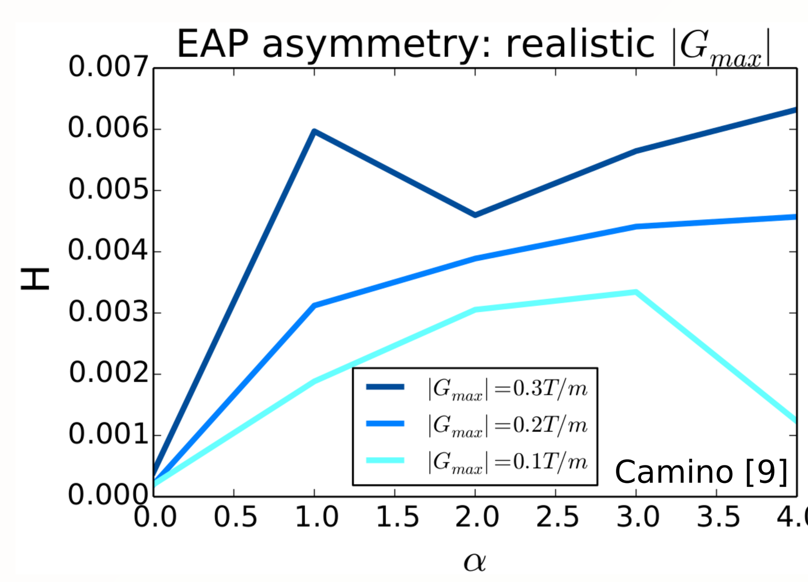


As the tortuosity variation rate **α** increases (from left α=0 to right α=8):
- axonal **compression** increases;
- EAP **asymmetry** (i.e. the difference between upper and lower lobes) increases.

6 Asymmetry quantification

As the tortuosity rate **α** (i.e compression) increases the calculated EAP asymmetry increases. EAP asymmetry might be used as bio-marker for axonal compression.





$$H^2 = \frac{1}{2}\int \left(\sqrt{\mathrm{EAP}(\mathbf{r}|t_d)} - \sqrt{\mathrm{EAP}(-\mathbf{r}|t_d)}\right)^2 d\mathbf{r}$$

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References

[1] Assaf et al., MRM, 59(6), 1347-1354 (2008); [2] Zhang et al., Neuroimage, 61 (4), 1000-1016 (2012); [3] Alexander et al. MRM, 60(2), 439-448 (2008); [4] Nilsson et al., NMR in Biomedicine, 25 (5), 795 (2012); [5] Shacklock, Neurodynamics Solutions, Adelaide (2007); [6] Tanner et al., JCP, 49(4), 1768- -1777 (1968); [7] Özarslan et al., MRI, 27(6), 834-844(2009); [8] Hellinger, JfdRuaM (1909); [9] Hall et al., IEEE TMI, Vol. 28, pp. 1354-1364 (2009); [10] Bracewell, (2000).

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